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Modeling of short duration extreme rainfall events over Lower Yamuna Catchment

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सार – हाईड्रॉलिक संरचनाओं के लिए बाढ़ डिजाइनिंग, शहरों में आने वाली बाढ़ आदि जैसे कई प्रकार के कार्यों को पूरा करने के लिए अल्प अवधि वर्षा के आकलन और प्रत्यागमन कालों में उनकी तीव्रताओं की आवश्यकता पड़ती है। इस शोधपत्र में यमुना के निचले जलग्रहण क्षेत्रों में अल्पअवधि वाली वर्षा की चरम घटनाओं का मॉडल बनाने का प्रयास किया गया है। इस शोध पत्र में 5, 10, 15, 30, 45 और 60 मिनटों की अल्प अवधि वाली तूफानी वर्षा हेतु ई. वी. आई. वितरण का उपयोग करते हुए वार्षिक चरम वर्षा की श्रृंखलाओं और उनकी तीव्रताओं का विश्लेषण किया गया और विभिन्न प्रत्यागमन कालों को आकलित किया गया। इस अध्ययन में यमुना के निचले जल ग्रहण क्षेत्र (एल. वाई. सी.) में वर्ष 1988–2009 की अवधि के स्वतः अभिलेखित वर्षा मापी (एस. आर. आर जी. एस.) के आकड़ों का उपयोग किया गया है इसमें यह देखा गया है कि ई. वी. आई. वितरण उपयुक्त पाए गए है और प्रत्येक स्टेशन के लिए महत्ता की दृष्टि से 5 प्रतिशत स्तर पर कोल्मोगोरोव स्मिरनोव अपयुक्तता के परीक्षण के अनुसार अनुकूल पाए गए हैं।

ABSTRACT. Short duration rainfall estimates and their intensities for different return periods are required for many purposes such as for designing flood for hydraulic structures, urban flooding etc. An attempt has been made in this paper to Model extreme rainfall events of Short Duration over Lower Yamuna Catchment. Annual extreme rainfall series and their intensities were analysed using EVI distribution for rainstorms of short duration of 5, 10, 15, 30, 45 & 60 minutes and various return periods have been computed. The Self recording rainguage (SRRGs) data for the period 1988-2009 over the Lower Yamuna Catchment (LYC) have been used in this study. It has been found that EVI distribution fits well, tested by Kolmogorov-Smirnov goodness of fit test at 5 % level of significance for each of the station.

Key words – Extreme rainfall series, Short duration, Modeling, EVI, Gumbel distribution, Kolmogorov-Smirnov.

1. Introduction

Modeling of extreme rainfall along with their intensities of short duration ≤ 1 hour etc. for various return periods for any region are required for many purposes such as for fixing the design floods, designing of water related structures, hydrological design of railway, road bridges and their protection works, design of culverts, drainage & storm sewers in urban areas, irrigation, flood control and flood forecasting. The design engineers, requires estimates of rainfall extremes of short duration specially ≤ 1 hour and in this field there have been limited studies. A large amount of the variability of rainfall is due to the occurrence of extreme rainfall events. Therefore, the amount of extreme rainfall events over different parts of the area under study are needed. The study of spatial variability of extreme rainfall events helps to identify the areas of high and low values. The Rainfall frequency maps of India (Harihara Ayyar and Tripathi, 1974) published by India Meteorological department for different duration and also India Meteorological department 2009 published Atlas of State wise Genaralised Isopluvial (Return Period) maps for 24 hrs give estimate of rainfall for different return periods. But these maps do not show values specially for short duration of the order of ≤ 1 hr, whereas it is observed generally that high rainfall intensities are occurred for short duration. Studies on short duration rainfall analysis have been carried out by Dhar and Kulkarni [1970 (b), 1971) over U.P. & south India respectively, Dhar & Ramchandran [1970 (a)] over Kolkata. The Extreme value type I (Gumbel, 1958) distribution is one of the most widely used model for the probabilistic characterization of a variety of extreme

TABLE 1 (a-f)

Statatistical Rainfall intensity (RI) estimates (mm/hr) of annual extreme series

(a) RI for rainstorms of 5 minutes duration

S. No.	Station (Dist.) Lat./ Long.	No. of years of record	Kolmogorov-Smirnov statistic D	Mean	C.V. (%)	Maximum	Return periods in years					
							2	5	10	25	50	100
1.	Poiyaghat (Agra) 27° 16′ N 78° 02′ E	15	0.25403	120	14	144	108	132	131	144	156	168
2.	Rajghat (Lalitpur) 24° 50′ N 78° 12′ E	16	0.2559	132	32	240	132	168	204	228	264	288
3.	Nautghat (Jhansi) 25° 22′ N 78° 37′ E	16	0.2559	108	33	156	108	132	156	180	204	216
4.	Mohana (Betwa) 25° 42′ N (Jalaun) 79° 22′ E	17	0.2763	120	28	180	120	144	168	198	216	228
5.	Auraiya (Auraiya) 26° 26′ N 79° 25′ E	19	0.24468	120	26	180	108	132	156	180	192	204
6.	Kalpi (Jalaun) 26° 12′ N 79° 42′ E	17	0.24811	108	33	168	96	132	156	180	192	216
7.	Kaimaha (Mahoba) 25° 06′ N 79° 50′ E	19	0.1733	132	24	204	132	156	180	204	216	240
8.	Banda (Banda) 25° 29′ N 80° 18′ E	18	0.26063	144	32	240	132	168	192	216	240	264
9.	Chillaghat (Banda) 25°47′ N 80° 31′ E	22	0.19782	132	37	240	120	168	192	228	252	276

(b) RI for rainstorms of 10 minutes duration

S. No.	Station	Kolmogorov-Smirnov statistic D	Mean	C.V. (%)	Maximum	Return periods in years					
						2	5	10	25	50	100
1.	Poiyaghat	0.17247	96	27	132	90	114	132	150	162	174
2.	Rajghat	0.1475	108	31	180	102	132	150	174	192	210
3.	Nautghat	0.2714	90	36	132	84	108	126	150	168	186
4.	Mohana (Betwa)	0.17728	102	29	180	96	126	144	162	180	198
5.	Auraiya	0.1264	90	34	168	72	114	132	156	168	186
6.	Kalpi	0.2636	96	28	120	90	114	132	150	162	180
7.	Kaimaha	0.24835	108	23	150	102	126	138	156	174	186
8.	Banda	0.11173	108	36	180	102	138	162	192	216	234
9.	Chillaghat	0.12885	102	33	180	96	126	144	168	192	210

(c) RI for rainstorms of 15 minutes duration

S. No.	Station .	Kolmogorov-Smirnov statistic D	Mean	C.V. (%)	Maximum	Return periods in years					
						2	5	10	25	50	100
1.	Poiyaghat	0.1924	80	28	124	76	96	108	124	136	148
2.	Rajghat	0.1770	96	27	160	92	116	132	152	164	180
3.	Nautghat	0.1561	80	37	120	76	104	120	144	160	174
4.	Mohana (Betwa)	0.13461	92	29	140	88	112	128	148	148	180
5.	Auraiya	01439	80	33	140	76	100	116	132	148	164
6.	Kalpi	0.19354	92	26	120	88	104	120	140	152	164
7.	Kaimaha	0.17538	100	26	140	96	116	132	152	168	180
8.	Banda	0..18323	92	36	152	88	116	136	160	180	196
9	Chillaghat	0.25182	92	30	160	88	112	128	148	164	180

(d) RI for rainstorms of 30 minutes duration

S. No.	Station	Kolmogorov-Smirnov statistic D	Mean	C.V. (%)	Maximum	Return periods in years					
						2	5	10	25	50	100
1.	Poiyaghat	0.13837	60	30	100	58	74	84	96	106	116
2.	Rajghat	0.1401	70	32	132	66	86	98	114	128	140
3.	Nautghat	0.1382	62	42	96	58	82	96	116	130	144
4.	Mohana (Betwa)	0.12009	72	27	112	68	84	96	110	120	130
5.	Auraiya	0.1153	60	39	110	56	76	90	108	120	134
6.	Kalpi	0.1739	70	31	100	66	84	98	114	126	138
7.	Kaimaha	0.19577	72	27	120	68	86	96	110	122	132
8.	Banda	0.18002	66	39	136	62	86	100	120	134	148
9	Chillaghat	0.09548	68	31	120	64	82	94	110	120	132

(e) RI for rainstorms of 45 minutes duration

S. No.	Station	Kolmogorov-Smirnov statistic D	Mean	C.V. (%)	Maximum	Return periods in years					
						2	5	10	25	50	100
1.	Poiyaghat	0.15903	39	34	94	47	61	72	84	91	102
2.	Rajghat	0.1234	53	34	105	51	67	77	90	101	110
3.	Nautghat	0.2150	53	41	84	49	69	81	97	109	121
4.	Mohana (Betwa)	0.10440	56	28	87	53	67	75	87	94	102
5.	Auraiya	0.1288	51	38	93	48	65	77	92	102	113
6.	Kalpi	0.12031	60	30	93	58	73	84	98	108	118
7.	Kaimaha	0.15432	57	27	100	55	69	75	89	97	106
8.	Banda	0.13813	53	42	115	49	69	81	98	110	122
9	Chillaghat	0.19782	55	35	126	52	69	80	94	105	116

(f) RI for rainstorms of 60 minutes duration

S. No.	Station	Kolmogorov-Smirnov statistic D	Mean	C.V. (%)	Maximum	Return periods in years					
						2	5	10	25	50	100
1.	Poiyaghat	017952	42	35	80	40	53	61	72	80	88
2.	Rajghat	0.1390	47	32	81	44	58	67	78	86	94
3.	Nautghat	0.1822	47	43	80	44	62	74	90	101	112
4.	Mohana (Betwa)	0.23304	46	30	73	44	56	64	75	82	90
5.	Auraiya	0.1190	42	35	70	39	52	60	71	79	87
6.	Kalpi	0.13694	50	31	75	47	61	70	82	90	98
7.	Kaimaha	0.19328	49	29	92	46	59	67	78	86	93
8.	Banda	0.1294	45	38	88	42	57	68	80	90	99
9	Chillaghat		48	37	110	45	60	71	84	93	103

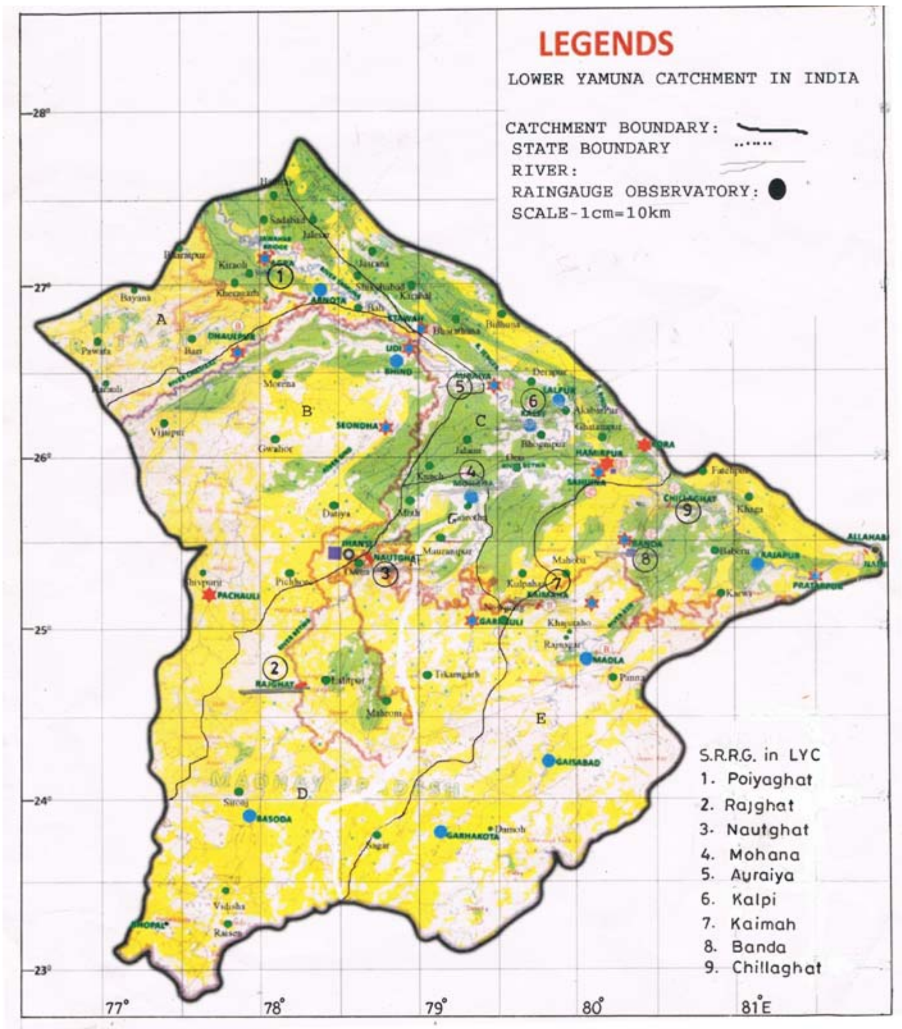


Fig. 1. Location of self recording raingauges Hydro-meteorological observatories in Lower Yamuna Catchment

hydro meteorological rainfall series. Rao *et al.* (1983) in his paper over lower Godavari basin presented a technique to estimate short duration extreme rainfall for a given return periods from daily (24 hr) rainfall records for any area. Harihara Ayyar and Tripathi (1973) suggested in his study that a daily rainfall estimate should be converted in to any 24 hr rainfall estimate by multiplying by a factor of 1.15 and then a relationship already established should be used to deduce short duration rainfall estimate for each station. Singh (1989) found EVI as a better distribution than gamma in his study at Colaba, Bombay, for extreme series using estimated parameters by moments and maximm likelihood method. Goel and Kathuria (1984) applied the Gumbel Fisher & Tipper type II distribution to annual extreme rainfall series over Krishna basin, Mukherjee *et al.* (1991) for extreme rainfall concluded that extreme value type I distribution fits adequately the annual maximum (daily) rainfall series over most of the country except for west Rajasthan and Saurashtra & Kutch. In this paper, EVI distribution has been fitted to rainfall extreme series and their intensities (mm/hr) of short duration 5, 10, 15, 30, 45 and 60 minutes using method of moments and the spatial variation is also presented.

2. Methodology

The Cumulative function is given by

$$F(x) = \exp\left[-\exp\{-(x-u)/\alpha\}\right], \qquad \alpha, u > 0, \; -\infty < x < \infty \qquad (1)$$

Where x represents the extreme rainfall series and α & u are the shape and location parameters of the distribution respectively. In terms of the reduced variate $Y = (x-u)/\alpha$, Eqn. (1) becomes:

$$F(x) = \exp[-\exp(-Y)] \quad (2)$$

If X_T is the T-year event value of the variable x, and Y_T the corresponding value of reduced variate Y, Eqn. (2) becomes :

$$F(x) = 1 - 1/T = \exp[-\exp(-Y_T)] \quad (3)$$

$$\text{Then, } Y_T = -\ln\ln[T/(T-1)] \quad (4)$$

$$\text{and } X_T = u + \alpha Y_T \quad (5)$$

The rainfall estimate for a particular return period (T) may be calculated by the equations 4 & 5. The standard error for the rainfall estimate is given by:

$$SE(X_T) = 1/\alpha N^{1/2} \ (1.11 + 0.52\, Y_T + 0.61\, Y_T^2) \quad (6)$$

Among from the several methods, in this paper selected the method of moments to fit EVI distribution to the extreme of SRRG hydro-meteorological observatories (HMO) listed in Table 1 in the LYC region. The moments estimators of the parameter α and u of the EVI distribution are as follows:

$$\alpha = \text{S.D.}\ \sqrt{6}/\pi = 0.7797 \times \text{S.D.}$$

$$u = \bar{x} - \text{S.D.}\ v\ \sqrt{6}/\pi = \bar{x} - 0.45 \times \text{S.D.}$$

(v = Euler's constant = 0.5772)

Where $\bar{x}$ and SD are the mean and standard deviation of the extreme series.

3. Data and analysis

3.1. *Fitting of annual extreme rainfall series*

The annual extreme rainfall series have been constructed by extracting the highest rainfall by analyzing the daily autographic 24 hourly rainfall data for durations of 5, 10, 15, 30, 45, 60 minutes at 9 HMO stations under LYC region listed in Tables 1(a-f) for the period (1988-2009), the period of data varied from 15 to 22 years which are shown in the Table 1 (a) stating the no. of years of records. The location of these Self Recording Rain Gauges (SRRGs) in LYC are shown in Fig. 1. These annual extreme series for the above mentioned durations at each station were subjected to frequency analysis by EVI using the method of moments and the rainfall estimates of different return periods *viz*., 2, 5, 10, 25, 50 & 100 years for different durations were obtained by using Eqns. 4 & 5 and the corresponding standard errors [SE (X_T)] computed by using the Eqn. 6.

The different estimates (X_T) so computed for various short duration were plotted on probability paper for EVI distribution along with confidence limit (± 2SE) for each station. The observed extreme rainfall values for each HMO were also plotted on the probability paper by using Gringorton's (1963) plotting position using empirical expression for return period T as

$$T = N + 0.12 / \text{m} - 0.44 \quad (7)$$

Where m is the rank of the observed series arranged in descending order and N is the total no. of observations. It is observed from these plots as depicted in Figs. 2 (a-r) that EVI distribution fits satisfactorily because the observed rainfall values are lying between the confidence intervals for each station.

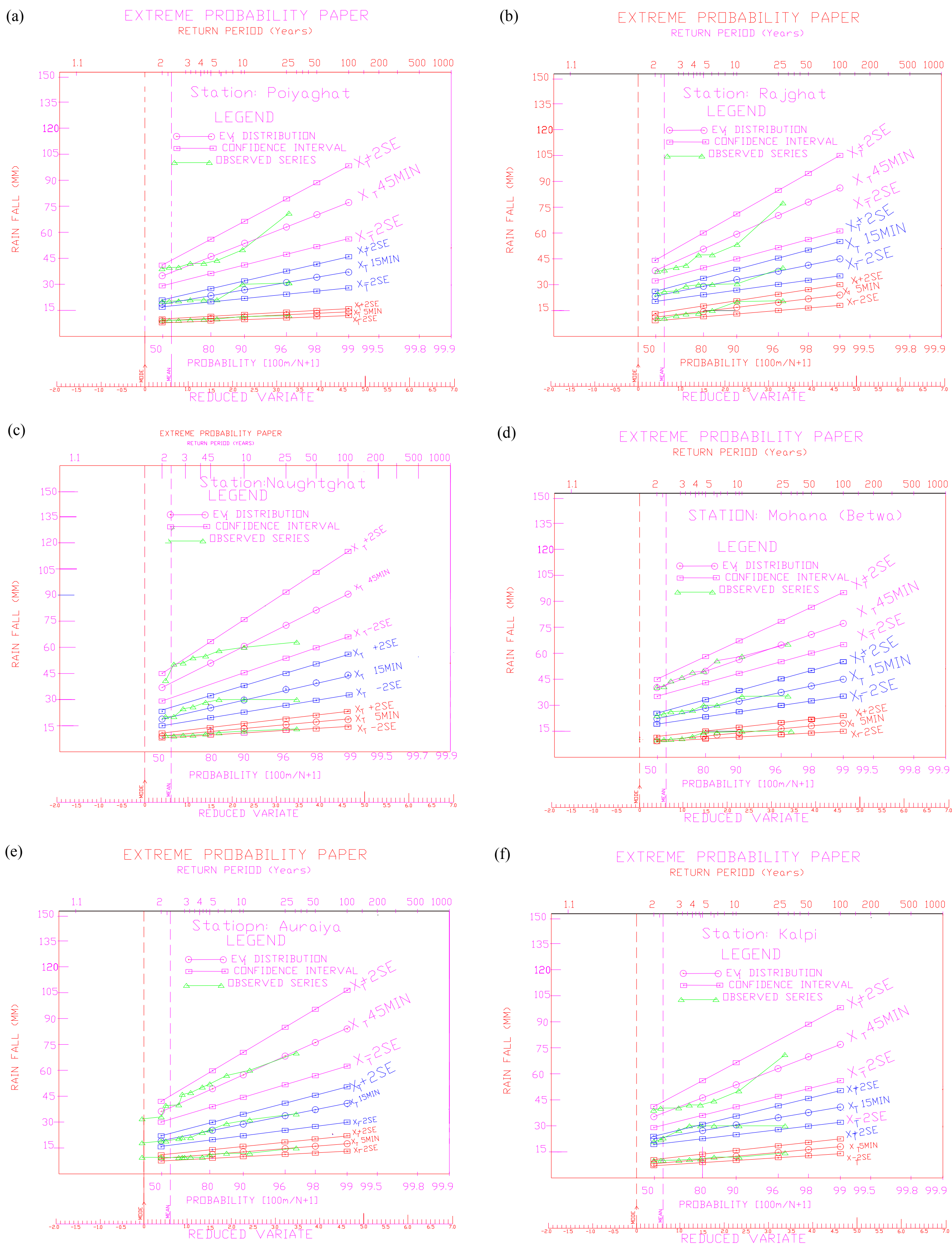
3.2. *Descriptive rainfall intensities statistics*

From the daily rainfall series annual maximum rainfall intensities (RI) in mm/hr of rainstorms of duration 5, 10, 15, 30, 45, 60 minutes are constructed for each of the 9 stations, Tables 1 (a-f) show their Maximum, Mean & C.V. (%) values.

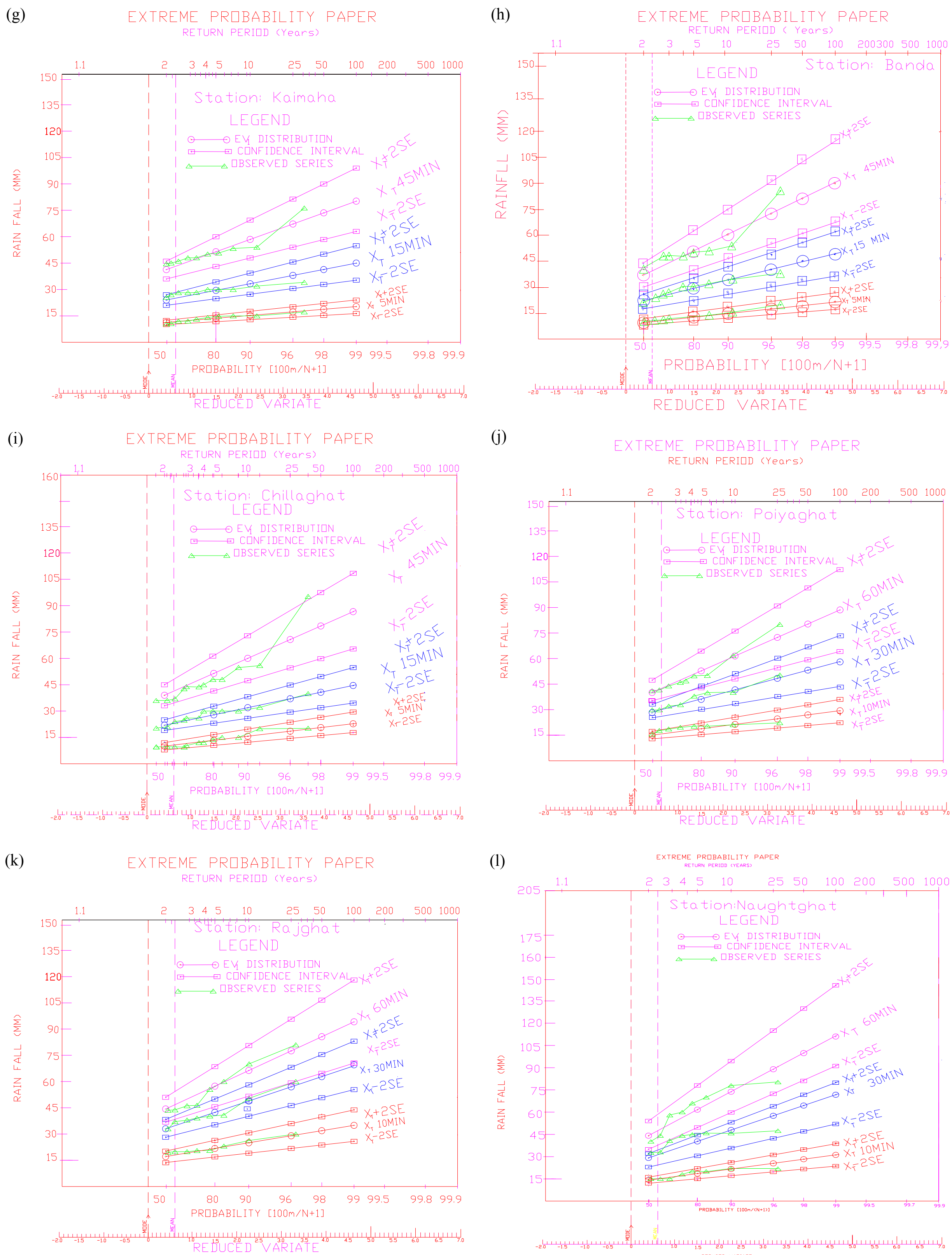
(a) For 5 minutes duration of annual extreme series at various stations, Maximum RI over the stations shows variation from 144 mm/hr at Poiyaghat to 240 mm/hr over Banda and Chillaghat. This variation decreases as the duration of rainstorm increases.

(b) The lowest C.V. of 14% is observed at station Poiyaghat and highest C.V. of 37% is observed at station Chillaghat (Banda) of 5 minutes duration rainstorms. Thus variability of RI of rainstorm of 5 minutes duration is high in the area of high value of extreme RI and *vice-versa*.

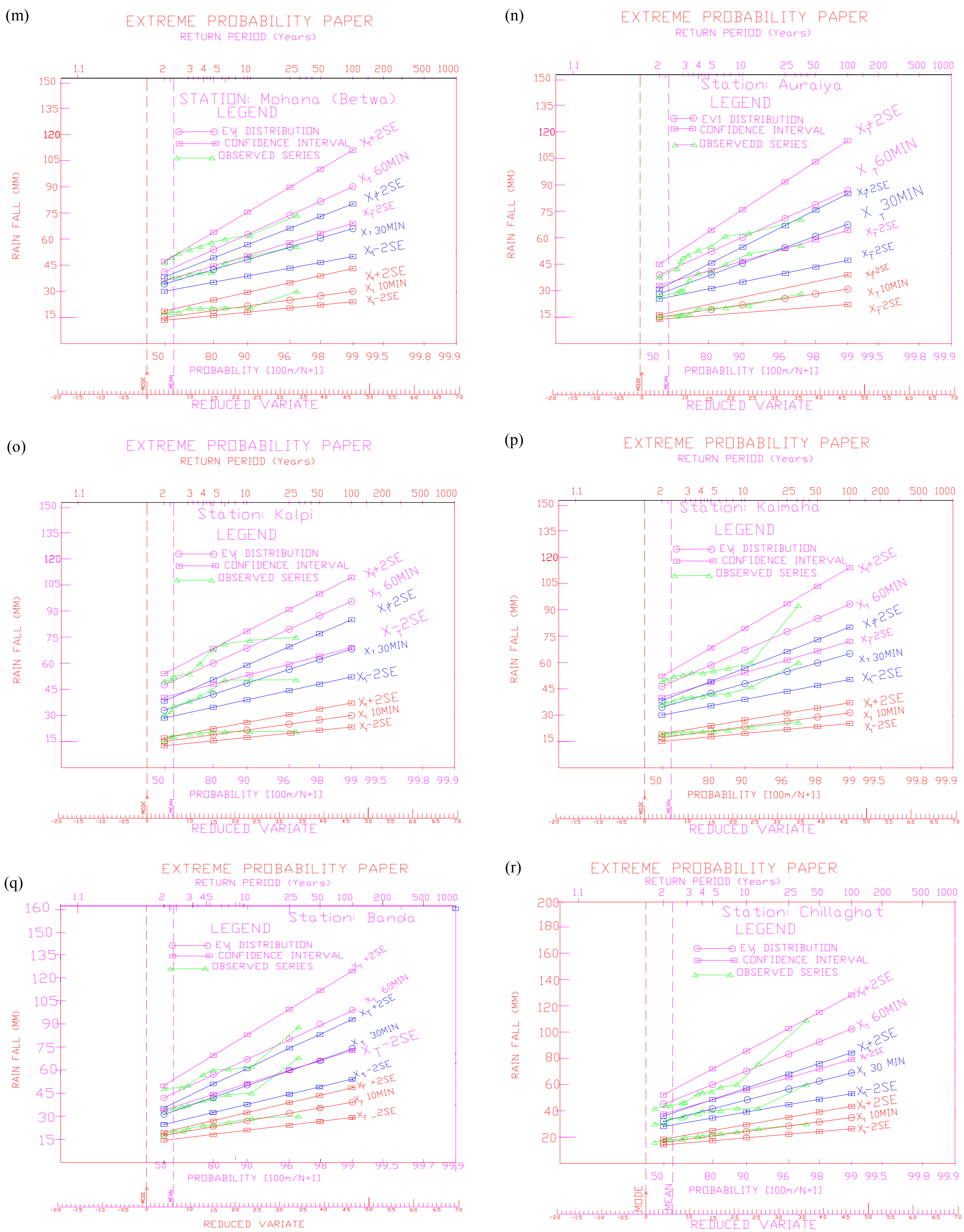
(c) Generally C.V. value increases as duration of rainstorms increases at station Poiyaghat, Naughtghat, Kaimah and Banda while at Chillaghat station, first it decreases from duration 5 minutes to 15 minutes and then it increases as duration increases, for remaining stations its values fluctuate.



Figs. 2(a-f). *Contd.*



Figs. 2(g-l). *Contd.*



Figs. 2 (a-r). Fitting of EVI distribution to the annual extreme rainfall series of duration (a-i) 5, 15 & 45 minutes and (j-r) 10, 30 & 60 minutes respectively for different stations

3.3. *Spatial distribution of Rainfall intensities of extreme rain events*

The estimates of RI have been computed up to 100 years return period. Using the method of moments, the rainfall intensities (RI) for each station for different return periods (R.P.) of 2, 5, 10, 25, 50 and 100 years are obtained for rainstorms of short durations *viz*., 5 minutes, 10 minutes, 15 minutes, 30 minutes, 45 minutes, 1 hour, these are presented in Tables 1 (a-f). From these tables, emerge that:

(a) The magnitude of RI decreases as the duration of the rainstorms increases. The station Poiyaghat (Agra) has the minimum R.P. value and the station Banda has maximum R.P. value for most of the duration of rainstorms. This resembles with the pattern of normal rainfall features *i.e*., the amount of rainfall increases from west to east along LYC region.

(b) The highest RI (mm/hr) of 132 for rainstorm of 5 minutes duration has been observed over stations Banda, Kaimah & Rajghat for 2 year return period while for 100 years R.P. value, it enhances to 288 (mm/hr).

(c) The variation in the value of RI over LYC decreases as duration increases and it increases as R.P. value increases.

(d) The Kolmogorov-Smirnov goodness of fit test was used for testing the fitting of EVI distribution. Tables 1 (a-f) also depicts the Kolmogorov-Smirnov goodness of fit statistic D computed from the time series of annual extreme RI of duration 5, 10, 15, 30, 45 minutes & 1 hour The values are compared with the tabular values and these supported the hypothesis that EVI distribution can not be rejected at 5% level of significance for each of station in the LYC. Thus EVI distribution is a good fit for series of annual extreme of RI of various duration discussed above.

4. Conclusion

Modeling of extreme rainfall and their intensities for short duration (5, 10, 15, 30, 45 & 60 minutes) have been estimated using EVI distribution. The following points concluded:

(a) Generally the high value of extreme RI of rainstorms of various duration are observed along the eastern side of the catchment and low value along western side of LYC. This resembles with normal rainfall pattern. Also the lowt CV observed in western side and high CV value are toward eastern side in LYC region.

(b) The variation in extremes RI decreases as duration increases.

(c) Annual extreme rainfall and their intensities have been analysed for all stations by EVI distribution over LYC and concluded that EVI distribution fits adequately well over LYC as tested by Kolmogorov-Smirnov goodness of fit test.

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